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# Wrenching Douglas-Fir Seedlings In August: Immediate But No Lasting Effects

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# Abstract


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Effects of wrenching Douglas-fir seedlings in August of their second season in the D. L. Phipps State Forest Nursery, Elkton, Oregon, were determined by periodic samplings to learn of changes in phenological, morphological, and growth characteristics. Initial effects of wrenching moderated by January when seedlings were lifted; both wrenched and unwrenched seedlings had grown substantially larger. Survival and growth of seedlings were good during the first 5 years after outplanting in droughty skeletal soil on southeast and northeast slopes in the South Umpqua River drainage of southwestern Oregon, and no significant differences were found between wrenched and unwrenched seedlings. A difference in total tree height on the two slopes was caused by greater browsing on the southeast slope.



Keywords: Regeneration, wrenching, nursery practices, seedling growth, browsing (-regeneration, Douglas-fir, *Pseudotsuga menziesii.*


# Summary


Responses of Douglas-fir seedlings in the nursery and after outplanting were determined following a single wrenching in August of their second season. It was premised that wrenching in early August would favorably influence root morphology and conditioning of seedlings, yet avoid the drastic growth reductions that often result from wrenching earlier in the growing season.

Seedlings used in the study had been grown following standard production practices at the D. L. Phipps State Forest Nursery, Elkton, Oregon, from seed obtained in seed zone 492 in the South Umpqua River drainage. During late summer and early autumn, wrenched and unwrenched seedlings were sampled at intervals from single bed segments for measurement of seedling size and for growth tests in a greenhouse and in raised beds outdoors. The entire bed of nursery stock was lifted in mid-January 1977; samples were again taken for measurement and growth tests, but in addition, 100 wrenched and 100 unwrenched seedlings were planted immediately on two droughty sites in skeletal soil of the Beekman series near Days Creek, Oregon.

Top and root status of wrenched and unwrenched seedlings differed 24 days after wrenching, and their subsequent phenology and growth did not proceed in parallel through late summer, autumn, and early winter. Growth of wrenched seedlings slowed down for a brief period and then resumed vigorously in early autumn whereas growth and hardening of unwrenched seedlings proceeded more steadily. Active root growth was found on wrenched and unwrenched seedlings at most sampling dates.

At first, shoot length of wrenched seedlings was shorter, shoots and roots were lighter, and number of lateral roots over 1 cm (0.4 in) long was less than for unwrenched seedlings. However, 145 days later, wrenched seedlings had longer shoots and a lower shoot:root ratio, but were similar to unwrenched seedlings in other respects. Large changes occurred in size of both wrenched and unwrenched seedlings

between late August and mid-January: linear regression equations describe these changes for six seedling attributes. The greatest change was a fivefold increase in ovendry weight of roots for wrenched seedlings.

Growth of seedlings transplanted to pots and raised beds indicated that both wrenching and lifting time were important influences. Growth of wrenched seedlings from the first two samplings was less than of unwrenched seedlings; differences for later samplings narrowed. The later in the season both wrenched and unwrenched seedlings were lifted, the greater their subsequent growth. Seedlings lifted in January also flushed earliest and most vigorously.

There was no difference in 5-year field survival and growth of wrenched and unwrenched seedlings. Survival was 90 percent on the southeast slope and 85 percent on the northeast slope. Seedlings averaged nearly 1 m tall (3.2 ft) and 14 mm (0.5 in) in diameter at 30 cm (12 in) above mean ground level. A significant difference in seedling height on the two slopes was found to be the result of browsing. Unbrowsed trees were the same height on both slopes, but total height of browsed trees was significantly lower on the southeast slope.

Nearly all studies of wrenching effect have reported that wrenching alters growth and physiology of Douglas-fir, but its influence on field performance has ranged from highly favorable to unfavorable. Wrenching is only one of the nursery practices that, in combination, conditions seedlings for outplanting. Factorial studies are in progress that test the combined effects of nursery practices In successive crops and outplantings.

## Introduction

Production techniques used in the nursery can drastically influence the physical and physiological characteristics of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings. Several studies in the past decade have investigated the effects of seedbed density, undercutting, and irrigation practices on seedling size, characteristics, and performance (Duryea and Lavender 1982; Edgren 1976; Koon and O'Dell 1977; Menzies 1980; Tanaka and others 1975, 1976; Van Den Driessche 1983). In this study, responses of Douglas-fir seedlings in the nursery and after outplanting in skeletal soils were determined following a single wrenching in August of the second season.

Interest in wrenching Douglas-fir was stimulated in the Pacific Northwest by the improved survival and growth of Monterey pine (*Pinus radiata* D. Don) that was obtained using this practice in New Zealand (Dorsser and Rook 1972; Rook 1969, 1971). Wrenching involves passing a tilted blade or an oscillating bar under the seedbed to sever seedling roots and aerate the soil. The intended effects are to slow seedling height growth, stimulate lateral root development, and attain better balance between tops and roots. Key factors that influence wrenching results include initial size of seedlings, wrenching depth, and timing relative to stage of seedling development and to date of lifting. It was premised that wrenching in early August would favorably influence root morphology and conditioning of seedlings, yet avoid the drastic growth reductions that often result from wrenching earlier in the growing season.

## Methods

### Seedling Production

Seedlings used in the study were grown at the D. L. Phipps State Forest Nursery at Elkton, Oregon. Origin of the seed was from the 610-m (2,000-ft) elevation in seed zone 492 on lands managed by the Bureau of Land Management, U.S. Department of the Interior, in the South Umpqua River drainage southeast of Roseburg, Oregon.

The nursery's usual first- and second-year production practices were applied in growing seedlings from this lot. During the 1976 season, beds of seedlings were undercut at 15 cm (6 in) in late April, vertically root pruned in early June, and fertilized with 303 kg/ha (250 lbs/ac) of 27-12-0 fertilizer in April and May. Seedlings were watered sufficiently in the first half of the growing season to foster height growth. They developed at moderate bed density, about 323/m$^2$ (30/ft$^2$). On August 2, 1976, 15.2 lineal m (50 lineal ft) of nursery bed containing lot 492 were wrenched at the 18-cm (7-in) depth with an oscillating wrenching blade. A 15.2-m segment of the same bed was left unwrenched for comparison. The two adjoining segments were selected for their similarity in size and density of seedlings. Moisture stress in the wrenched seedlings averaged 12.25 bars before dawn the next day. As a general practice, Phipps Nursery relieved stresses over 12 bars by watering; thus, the entire bed of seedlings was irrigated for 2 hours on August 3.

### Size Determinations

During late summer and early autumn, wrenched and unwrenched seedlings were sampled at intervals—on August 26, September 14, October 5, and October 29. Another sample was taken on January 18, 1977, when the entire bed of seedlings was lifted. On the first four dates, seedlings were dug with a tile spade; on the final date, they were loosened by machine at the 25-cm (10-in) depth. At each lifting, trees were taken from 4 well-spaced points in the wrenched or unwrenched bed segment separately and systematically allotted to 10-tree subsamples. Each subsample (bundle) received a nearly equal number of seedlings from each sampling point.

Roots of bundled trees were pruned to a 25-cm (10-in) length. Bundles of trees were then randomly designated for different purposes—measurement of seedling size, growth test in a greenhouse and in a raised bed outdoors and, for seedlings of the January lifting only, a test planting in the forest. Bundles of seedlings were put in plastic bags and transported to Corvallis, Oregon, or to the field in chests that were cooled with ice in warm weather.

Forty wrenched and 40 unwrenched seedlings from each lifting were measured for shoot length and stem diameter, counted for number of lateral roots 1 cm (0.4 in) or longer, and observed for presence of a terminal bud, light green foliage on terminal or lateral tips, and actively growing white roots. Shoot length in centimeters was determined by measuring from the base of the terminal bud to the root collar. The root collar was defined as located 1 cm (0.4 in) below the cotyledonal scars.

Stem diameter was measured to the nearest tenth of a millimeter at the root collar. The first 20 seedlings of each group were dried at 70°C (158°F) in a drying oven for 48 hours. Ovendry weight of top and root was determined to the nearest 0.01 gram, and shoot:root ratio (ovendry weight basis) was later calculated for each of these seedlings. All size data were summed, differences between treatment means for single dates and for all dates together were tested by analysis of variance, and changes over time were examined by regression techniques.

## Growth Tests

Promptly after each lifting, 20 wrenched and 20 unwrenched seedlings were potted, and the pots were placed in random arrangement on a greenhouse bench. Large fiber pots were used, and 10 seedlings of a single treatment were planted in each one. The seedlings were maintained under well-watered greenhouse conditions from time of potting until May 13, 1977; observations on phenology and survival were made on March 3, March 22, and April 28, 1977. Height growth on seedlings lifted in January 1977, nearly all of whose terminal buds flushed normally, was measured on May 13, 1977. Observations then ended on these four pots of seedlings.

Potted seedlings of the earlier four liftings, whose terminals did not flush for lack of chilling, were subjected to a 60-day chilling period at 1°C (34°F) in an unlighted cooler and then placed outdoors and watered regularly for the remainder of the growing season. Survival and the 1977 growth response of the chilled seedlings was measured the next spring on May 17, 1978.

Twenty wrenched and twenty unwrenched seedlings from each lifting were also planted promptly in two raised outdoor beds, ten of a single treatment per row. The seedlings were watered just enough in late summer and autumn to prevent drought damage. They overwintered outdoors, and their appearance and flushing were observed on March 4, March 25, and May 3, 1977. Seedlings were watered regularly during the growing season of 1977. Their survival and height growth were determined on October 5, 1977. Treatment and lifting time differences in shoot growth data for these seedlings, and also for those of potted seedlings, were compared by analysis of variance and regression methods.

Two hundred seedlings from the January lifting were planted the same day on two field sites located southeast of Roseburg, Oregon, in Township 31 South, Range 4 West, Section 13, Willamette Meridan, on Bureau of Land Management lands. One hundred trees were planted on each site in a 2.4- x 2.4-meter grid (8 x 8 ft). Wrenched trees were planted at half the planting spots and unwrenched trees at the rest as randomly designated in advance. Two planters planted the trees; each planted wrenched and unwrenched trees as designated for individual spots in the rows. Trees were planted following normal good practice and were not shaded or otherwise protected. The weather was clear and sunny, but chilly, especially late in the afternoon on the northeast slope. Tree survival was first checked on May 25, 1977. Survival and initial and first-year height were determined on June 21, 1978; second-year survival and height on December 4, 1978; and fifth-year survival, height, and stem diameter on October 27, 1981. Growth data were tested by analysis of variance for differences due to treatment, slope, and browsing.

Both planting sites are located near 640-m (2,100-ft) elevation on soil of the Beekman series. This is a skeletal soil of the Klamath Mountains, moderately deep, very gravelly, loamy, and well drained, that originated from sedimentary and metamorphic rocks (Wert and others 1977). Average annual precipitation at the study sites is about 122 cm (48 in) with 13 cm (5 in) falling in the dry season, May through September (Froehlich and others 1982, McNabb and others 1982). One of the plantings was made on a moderately steep (40- to 50-percent) southeast slope (fig. 1), the other on a very steep (60- to 85-percent) northeast slope (fig. 2). Both areas had been clearcut and logged in the spring and summer of 1976, and slash was broadcast burned in autumn. The areas supported an open mixed-conifer stand of site IV quality, largely Douglas-fir with scattered incense-cedars (*Libocedrus decurrens* Torr.), and an understory of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Pacific madrone (*Arbutus menziesii* Pursh), and giant chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.

Perennial woody vegetation of variable density developed on these sites in competition with the Douglas-firs (fig. 2). After five years, the most prominent species included Pacific rhododendron (*Rhododendron macrophyllum* D. Don ex G. Don), Pacific madrone, giant chinkapin, bracken fern (*Pteridium aquilinum* (L.) Kuhn.), salal (*Gaultheria shallon* Pursh), trailing blackberry (*Rubus ursinus* Cham. & Schlecht.), snowbrush ceanothus (*Ceanothus velutinus* Dougl.), ocean spray (*Holodiscus discolor* (Pursh) Maxim.) and manzanita (*Arctostaphylos* sp.). Red alder (*Alnus rubra* Bong.), evergreen huckleberry (*Vaccinium ovatum* Pursh), willow (*Salix* sp.), sword fern (*Polystichum munitum* (Kaulf.) Presl), and whipplevine (*Whipplea modesta* Torr.) were more evident on the northeast slope than on the southeast slope. Such species as salal, bracken fern, and trailing blackberry were also more sparse and shorter on the southeast slope.

Figure 1.—The southeast slope was largely bare of vegetation in May 1977, 4 months after trees were planted. A clump of beargrass (*Xerophyllum tenax* (Pursh) Nutt.) is in the left foreground.

Figure 2.—A moderate cover of annual and perennial vegetation had developed on the steep northeast slope by June 1978.

## Results

### Phenological Changes

Top and root status of wrenched and unwrenched seedlings differed 24 days after wrenching, and the course of subsequent phenological events also differed through late summer and autumn (table 1). By late August, most wrenched seedlings had developed a terminal bud compared to only one-third of the unwrenched seedlings. By mid-September, nearly all seedlings sampled had terminal buds, but 3 weeks later only 60 percent of the wrenched seedlings had terminal buds. By late October, all seedlings had terminal buds, and such buds were universally present and prominent when seedlings were lifted in January.

Presence of light-green foliage at the tip of the terminal or lateral shoots, evidence of growth that occurred later than for other parts of the seedling, also reflected the phenological differences indicated by the terminal buds. Terminal shoots of wrenched seedlings were more active than those of unwrenched seedlings in October, but activity of lateral shoots was similar. Both wrenched and unwrenched seedlings showed some lighter green tips even in January.

Wrenched seedlings showed a high level of root activity at every sampling date except early October, whereas root activity of unwrenched seedlings increased from August onwards. Four out of five wrenched and unwrenched seedlings lifted in mid-January had root activity (five white root tips or more).

### Size Changes

Composite samples taken from the wrenched and unwrenched segment of the nursery bed indicated that seedlings differed significantly in size in late August, 24 days after wrenching (table 2). Shoot length of wrenched seedlings was shorter, shoots and roots were lighter, and number of lateral roots over 1 cm (0.4 in) long was less. Shoot:root ratio of wrenched seedlings was significantly larger.

**Table 1—Changes in phenology of wrenched and unwrenched seedlings in the nursery as shown by successive samplings**

| Phenological observation | Sampling date | | | | |
|---|---|---|---|---|---|
| | 8/26/76 | 9/14/76 | 10/5/76 | 10/29/76 | 1/18/77 |
| | Percent occurrence (N=40) | | | | |
| Terminal bud present: | | | | | |
| Wrenched | 93 | 100 | 60 | 100 | 100 |
| Unwrenched | 35 | 98 | 95 | 100 | 100 |
| Terminal foliage light green: | | | | | |
| Wrenched | 25 | 3 | 48 | 0 | 8 |
| Unwrenched | 38 | 10 | 8 | 8 | 8 |
| Lateral tip foliage light green: | | | | | |
| Wrenched | 10 | 0 | 50 | 3 | 15 |
| Unwrenched | 30 | 10 | 43 | 8 | 5 |
| Active root growth: | | | | | |
| Wrenched | 78 | 100 | 43 | 93 | 80 |
| Unwrenched | 35 | 45 | 65 | 73 | 80 |

**Table 2—Average shoot length, stem diameter, number of lateral roots, ovendry weight of tops and roots, and shoot:root ratio of wrenched and unwrenched seedlings at successive dates**

| Size attribute | Sampling date | | | | |
|---|---|---|---|---|---|
| | 8/26/76 | 9/14/76 | 10/5/76 | 10/29/76 | 1/18/77 |
| Shoot length (cm): | | | | | |
| Wrenched | 21.2 | 26.2 | 24.1 | 28.6 | 27.5 |
| Unwrenched | 23.9*[1/] | 26.1 | 23.3 | 23.0** | 25.1- |
| Stem diameter (mm): | | | | | |
| Wrenched | 3.3 | 3.9 | 4.4 | 4.8 | 5.2 |
| Unwrenched | 3.5 | 4.3- | 4.8* | 4.5 | 5.1 |
| Lateral roots (no.): | | | | | |
| Wrenched | 8.1 | 9.6 | 7.9 | 10.5 | 15.6 |
| Unwrenched | 10.9* | 8.3 | 7.6 | 7.6** | 16.0 |
| Shoot dry weight (gm): | | | | | |
| Wrenched | 2.4 | 3.7 | 2.9 | 5.3 | 5.8 |
| Unwrenched | 3.5- | 4.5 | 3.4 | 3.8- | 5.6 |
| Root dry weight (gm): | | | | | |
| Wrenched | 0.7 | 1.6 | 1.5 | 2.2 | 3.4 |
| Unwrenched | 1.2** | 1.5 | 1.4 | 1.7 | 3.0 |
| Shoot:root ratio: | | | | | |
| Wrenched | 3.5 | 2.4 | 2.1 | 2.5 | 1.7 |
| Unwrenched | 2.9** | 3.2*** | 2.5** | 2.3 | 1.9- |

1 cm equals 0.394 in; 1 mm equals 0.0394 in; and 1 gm equals 0.035 oz.

[1/]Data pairs sharing a dash (-) or 1, 2, or 3 asterisks differ significantly at the 90-, 95-, 99-, and 99.9-percent probability levels, respectively.

When lifted for planting 145 days later, however, size of wrenched and unwrenched seedlings was similar in most respects (table 2). Furthermore, wrenched seedlings tended to be larger but not significantly so except in shoot length (93 percent probability). They also had a slight but significantly lower (93 percent probability) shoot:root ratio (1.7 vs. 1.9). Thus, the nearly equal-sized wrenched and unwrenched seedlings planted in the field had dormant tops and prominent terminal buds, and 80 percent of them had white growing root tips. Their physiological differences in January were unknown.

Very large changes occurred in size of both wrenched and unwrenched seedlings between late August and mid-January. The changes were largely systematic and, thus, appear to represent more than the random variation among successive destructive samplings.[1/] Regression analyses show that there was a significant change with time in each size attribute for both wrenched and unwrenched seedlings with one exception, shoot length of unwrenched seedlings (table 3). The amount of variation accounted for in the regressions differs by attribute, is generally greater for wrenched seedlings, and in all instances accounts for less than 40 percent of the total variation.

Magnitude of some size changes merits individual notice. The root dry weight of wrenched seedlings changed fivefold; for unwrenched seedlings, about half that much. Shoot dry weight of wrenched seedlings increased by a factor of 2.4, of unwrenched seedlings by 1.6. The shoot:root ratio of wrenched seedlings decreased from 3.5 to 1.7, for unwrenched seedlings from 2.9 to 1.9.

[1/] Graphs illustrating changes in stem diameter, root dry weight, and shoot:root ratio were given in a preliminary report (Stein 1978).

**Table 3—Regressions between size attributes and days elapsed since wrenching for wrenched and unwrenched seedlings**

| Regression formula | | | | Statistical values[1/] | |
|---|---|---|---|---|---|
| Seedling attribute = | Constant | ± | Coefficient (elapsed days) | Cumulative $r^2$ | F ratio [2/] |
| Shoot length (cm): | | | | | |
| Wrenched seedlings | 22.79 | + | 0.03 (days) | 0.07 | 15.57*** |
| Unwrenched seedlings | 24.06 | + | 0.003 (days) | .00 | .12 |
| Stem diameter (mm): | | | | | |
| Wrenched seedlings | 3.34 | + | 0.01 (days) | .26 | 70.45*** |
| Unwrenched seedlings | 3.80 | + | 0.01 (days) | .12 | 26.28*** |
| Lateral roots (no.): | | | | | |
| Wrenched seedlings | 6.31 | + | 0.05 (days) | .25 | 64.81*** |
| Unwrenched seedlings | 6.60 | + | 0.04 (days) | .19 | 46.59*** |
| Shoot dry weight (gm): | | | | | |
| Wrenched seedlings | 2.27 | + | 0.02 (days) | .18 | 21.29*** |
| Unwrenched seedlings | 3.17 | + | 0.01 (days) | .07 | 7.80** |
| Root dry weight (gm): | | | | | |
| Wrenched seedlings | 0.50 | + | 0.02 (days) | .35 | 53.40*** |
| Unwrenched seedlings | 0.80 | + | 0.01 (days) | .26 | 34.39*** |
| Shoot:root ratio: | | | | | |
| Wrenched seedlings | 3.17 | - | 0.01 (days) | .33 | 48.46*** |
| Unwrenched seedlings | 3.23 | - | 0.01 (days) | .36 | 55.29*** |

[1/] In formulas for shoot length, stem diameter and number of lateral roots, degrees of freedom are 1 and 198; for the rest, 1 and 98.

[2/] 1 asterisk denotes significance of the regression F ratio at the 95-percent probability level; 2 asterisks, 99-percent; 3, 99.9-percent.

## Growth in Pots

Most seedlings that were potted immediately after lifting and placed in a greenhouse survived, but time of lifting influenced their subsequent phenology and growth (table 4). In late April 1977, 97 percent of wrenched seedlings and 92 percent of unwrenched seedlings were alive. More wrenched than unwrenched seedlings had a healthy appearance. Many of the unhealthy appearing seedlings seemed to have a fungus infection on the needles; those lifted in August were most affected.

Terminal and lateral buds of wrenched and unwrenched seedlings that were lifted in January 1977 flushed vigorously by late April. By the same date, terminal buds had flushed on only 3 of the 147 seedlings still alive from the first 4 liftings and lateral buds had flushed on only 29. To find out if they were still capable of flushing, these nondormant seedlings of the first four liftings were subjected to 60 days of chilling, then set outdoors. All but four seedlings survived this harsh treatment, and 93 percent made some growth in 1977; three more that did not flush in 1977 flushed in the spring of 1978.

Growth of potted seedlings varied significantly with lifting date; the later the seedlings were lifted, the more growth (probability greater than 99.9 percent). Those lifted in January, which required no chilling, grew substantially more than any receiving a delayed chill treatment. Growth was also significantly greater for unwrenched seedlings (probability 99.5 percent).

**Table 4—Response of wrenched and unwrenched seedlings potted immediately after lifting and maintained under growing conditions**

| Seedling response | Lifting date | | | | |
|---|---|---|---|---|---|
| | 8/26/76 | 9/14/76 | 10/5/76 | 10/29/76 | 1/18/77 |
| Seedlings alive (%): | | | | | |
| Wrenched | 85 | 100 | 100 | 100 | 100 |
| Unwrenched | 95 | 90 | 90 | 89 | 95 |
| Healthy appearance (%): | | | | | |
| Wrenched | 75 | 100 | 95 | 89 | 100 |
| Unwrenched | 20 | 85 | 80 | 78 | 90 |
| Terminals buds flushed (%): | | | | | |
| Wrenched | 5 | 0 | 0 | 5 | 100 |
| Unwrenched | 5 | 0 | 0 | 0 | 95 |
| Lateral buds flushed (%): | | | | | |
| Wrenched | 10 | 5 | 15 | 26 | 100 |
| Unwrenched | 20 | 10 | 25 | 39 | 95 |
| Average shoot growth (cm):1/ | | | | | |
| Wrenched | 2.4 | 2.6 | 3.0 | 4.3 | 9.4 |
| Unwrenched | 3.1-2/ | 3.6- | 3.5 | 5.9 | 10.3 |
| Increment relative to initial shoot length (%): | | | | | |
| Wrenched | 11 | 10 | 13 | 18 | 37 |
| Unwrenched | 14 | 14 | 18 | 24 | 41 |

1 cm equals 0.394 in.

1/Shoot growth for seedlings lifted 1/18/77 was determined 5/13/77; for the rest, 5/17/78.

2/Data pairs for average shoot growth sharing a dash (-) differ significantly at the 90-percent probability level.

## Growth in Outdoor Beds

At the March 4, 1977, examination, when terminal buds were still tight, seedlings had a range of color—those of the January lifting were deep green; those of the August lifting were barely medium green. Unwrenched seedlings of the August, September, and October liftings were also darker green than were the wrenched seedlings lifted on the same dates.

All seedlings that survived the 1977 growing season flushed in the spring. Bud swelling was evident by March 25 for seedlings from all liftings except those in August and September. Those lifted in January flushed earliest and most vigorously: in fact, rows of these seedlings could be spotted readily in the May 3 examination by their uniform flushing and greater amount of new growth. There was slight evidence that wrenched seedlings flushed a bit sooner than unwrenched seedlings, particularly for seedlings lifted in late summer and autumn.

First-year survival and growth was good in the outdoor beds for seedlings of all liftings (table 5). As with potted seedlings, height growth varied significantly with lifting date (probability 99.5 percent); the later seedlings were lifted, the more growth. Height increment of seedlings ranged from one-third to one-half of the initial height. Relative growth of wrenched and unwrenched seedlings varied by date (probability of interaction, 93.3 percent). An adverse effect of wrenching on height growth was indicated for the earlier liftings, but growth trends then converged.

**Table 5—First-year survival and average shoot growth of wrenched and unwrenched seedlings planted immediately after lifting in raised, outdoor beds**

| Seedling response | Lifting date | | | | |
|---|---|---|---|---|---|
| | 8/26/76 | 9/14/76 | 10/5/76 | 10/29/76 | 1/18/77 |
| Seedlings alive (%): | | | | | |
| Wrenched | 100 | 100 | 90 | 100 | 100 |
| Unwrenched | 80 | 80 | 95 | 90 | 95 |
| Average shoot growth (cm):[1] | | | | | |
| Wrenched | 7.1 | 7.7 | 8.0 | 10.0 | 11.5 |
| Unwrenched | 8.8 | 9.2 | 9.4 | 9.7 | 10.1 |
| Increment relative to initial shoot length (%): | | | | | |
| Wrenched | 31 | 32 | 31 | 50 | 44 |
| Unwrenched | 46 | 39 | 39 | 48 | 47 |

1 cm equals 0.394 in.

[1] Differences in average shoot growth for wrenched and unwrenched seedlings at individual dates are not significant at the 90-percent probability level.

## Growth in the Field

Survival of wrenched and unwrenched seedlings was good on both northeast and southeast slopes (table 6). At the end of 5 years, 87.5 percent of the seedlings planted were alive—90 percent on he southeast slope and 85 percent on the northeast slope. Most of the mortality occurred in the first season—9 percent of the total seedlings died compared to 3.5 percent after the first season. Survival of wrenched seedlings averaged only 3 percent more than for unwrenched seedlings.

During the infrequent reexaminations, cause of mortality was not evident on most dead seedlings. Mortality was scattered throughout the grids and showed no obvious pattern. Stress soon after planting caused some mortality; incidental causes included burial from loose soil, heavy shading from brush competition, and being covered by fallen dead poles. Only five seedlings that died had been browsed.

Five years after planting, seedlings averaged just under 1 m (3.2 ft) in total height and nearly 14 mm (0.5 in) in diameter at 30 cm (12 in) above mean ground level (table 7). Heights and diameters of wrenched and unwrenched seedlings did not differ significantly at the 90-percent probability level; in fact, their average heights were identical. Total height of unwrenched seedlings tended to be slightly greater after the first year (probability 85 percent) but this initial advantage disappeared.

Total height of seedlings but not stem diameter tended to differ on the two slopes (probability 88 percent). Seedlings on the northeast slope averaged 102 cm (3.3 ft) in height; those on the southeast slope averaged 94 cm (3.1 ft).

**Table 6—Field survival of wrenched and unwrenched seedlings in the first 5 years**

| Slope and treatment | Seedlings planted 1/77 | Seedlings alive 5/77 | 6/78 | 12/78 | 10/81 |
|---|---|---|---|---|---|
| | Number | Percent | | | |
| Southeast slope: | | | | | |
| Wrenched | 50 | 98 | 94 | 94 | 92 |
| Unwrenched | 50 | 100 | 94 | 90 | 88 |
| Northeast slope: | | | | | |
| Wrenched | 50 | 96 | 90 | 88 | 86 |
| Unwrenched | 50 | 100 | 86 | 86 | 84 |
| Total: | | | | | |
| Wrenched | 100 | 97 | 92 | 91 | 89 |
| Unwrenched | 100 | 100 | 90 | 88 | 86 |
| Average | | 98.5 | 91.0 | 89.5 | 87.5 |

**Table 7—Periodic total height of wrenched and unwrenched seedlings and fifth-year average diameter**

| Slope and treatment[1] | Total height 5/77 | 6/78 | 12/78 | 10/81 | Stem diameter |
|---|---|---|---|---|---|
| | Centimeters | | | | Millimeters |
| Southeast slope: | | | | | |
| Wrenched | 24.2 | 29.6 | 37.4 | 94.2 | 13.1 |
| Unwrenched | 24.9 | 31.5 | 38.3 | 93.3 | 14.7 |
| Northeast slope: | | | | | |
| Wrenched | 24.2 | 28.1 | 35.8 | 101.7 | 13.1 |
| Unwrenched | 24.5 | 29.2 | 38.0 | 102.5 | 13.5 |
| Total | | | | | |
| Wrenched | 24.2 | 28.9 | 36.6 | 97.8 | 13.1 |
| Unwrenched | 24.7 | 30.4 | 38.2 | 97.8 | 14.1 |
| Average and standard error | 24.5 $\pm$ 0.5 | 29.6 $\pm$ 0.5 | 37.4 $\pm$ 0.7 | 97.8 $\pm$ 2.6 | 13.6 $\pm$ 0.5 |

1 cm equals 0.394 in; 1 mm equals 0.0394 in.

[1]Differences between wrenched and unwrenched seedlings are not significant at the 90-percent probability level.

## Effects of Browsing

Fifty-six percent of surviving seedlings were browsed one or more times in the first 5 years. Browsed seedlings averaged 95 cm (3.1 ft) tall, unbrowsed seedlings 102 cm (3.3 ft) tall (table 8); the probability of a real difference is 82 percent. A majority of browsing damage occurred the first year; 83 trees were rated as browsed in the first examination, 18 were judged to have sustained damage between the first and second examinations, and 25 between the second and final examinations. Severity of damage in terms of amount of top removed tended to be light to moderate.

There was no selective browsing of wrenched or unwrenched trees, based on fifth-year height averages. In terms of numbers, a few more wrenched than unwrenched trees were browsed.

Browsing varied significantly by slope, however. A larger percentage of the trees planted on the southeast slope were browsed than of those planted on the northeast slope (62 vs. 49 percent). On the southeast slope, the average height of browsed trees was significantly less (probability 97 percent) than of unbrowsed trees—88 cm (2.9 ft) vs. 104 cm (3.4 ft). Average height of browsed and unbrowsed trees did not differ significantly on the northeast slope—104 cm (3.4 ft) vs. 100 cm (3.3 ft).

It is noteworthy that the average height of unbrowsed trees on the southeast slope was equal to (perhaps even greater) than for unbrowsed trees on the northeast slope. Site conditions are often considered more severe on southeast than on northeast slopes.

Browsed and unbrowsed trees did not differ significantly in average diameter.

**Table 8—Average total height at five years of unbrowsed and browsed, wrenched and unwrenched Douglas-firs**

| Slope and treatment[1/] | Unbrowsed Douglas-firs | | Browsed Douglas-firs | |
|---|---|---|---|---|
| | Trees | Height | Trees | Height |
| | Number | Centimeter | Number | Centimeter |
| Southeast slope: | | | | |
| Wrenched | 15 | 107.5 | 31 | 87.8 |
| Unwrenched | 19 | 100.5 | 25 | 87.8 |
| Northeast slope: | | | | |
| Wrenched | 21 | 96.6 | 22 | 106.5 |
| Unwrenched | 22 | 104.0 | 20 | 100.9 |
| Total: | | | | |
| Wrenched | 36 | 101.1 | 53 | 95.6 |
| Unwrenched | 41 | 102.4 | 45 | 93.6 |
| Total or average and standard error | 77 | 101.8 ± 4.0 | 98 | 94.7 ± 3.5 |

1 cm equals 0.394 in.

[1/]Differences between wrenched and unwrenched seedlings are not significant at the 90-percent probability level.

## Discussion and Conclusions

### Field Performance

Five-year survival of planted Douglas-fir was high on the two field sites. These sites, located on skeletal soil of the Klamath Mountains, were selected for the study because they are commonly considered to be difficult to regenerate with Douglas-fir. Survival of unshaded seedlings was 90 percent on the southeast slope, slightly higher than on the nearby steep northeast slope, even though the percentage of trees browsed was also greater. Annual precipitation at Days Creek during 1977, when most mortality occurred, was near normal, but precipitation during the growing season was substantially higher than normal.[2/] Planting the seedlings the same day they were lifted from the nursery was the only exceptional practice used in the study. Other practices were those used routinely at the time: nursery stock of local source lifted and outplanted while dormant, sites prepared by broadcast burning after clearcutting, and no postplanting vegetation control. Study results indicate that Douglas-fir can be established readily on Beekman soils in some years, but how consistently must still be determined.

The light to medium browsing sustained by trees in this study seems of minor consequence. Few browsed trees died, and the 7-cm (2.8-in) average difference in total height of browsed and unbrowsed trees is not likely to be important in the long run. Biological understanding has been improved, however, by knowing that browsing can cause seedling growth capability to appear different on southeast and northeast slopes.

[2/] Personal communication, Henry A. Froehlich, Oregon State University, Corvallis, July 27 and December 8, 1983.

### Wrenching Effects

Growth, morphological, and phenological data provide evidence that wrenching seedlings once in August had some short-term negative effects, but these effects soon moderated. Wrenching appears to have slowed seedling growth temporarily but then it resumed in autumn months more actively and with somewhat different timing than for unwrenched seedlings. Seedlings transplanted soon after wrenching did not have as much shoot growth capacity as unwrenched seedlings. Survival capacity may have been improved for seedlings transplanted soon after wrenching; mortality differences were small, but seedlings appeared healthier. The minor shoot length and shoot:root ratio differences in favor of wrenched seedlings at time of field planting had no long-term effect on seedling survival and growth.

Results of this study add some insight to the debate on the merits of wrenching for improving field survival and growth of Douglas-fir. Even a single wrenching late in the season curtailed growth and altered the physiology of Douglas-fir seedlings, a finding consistent with results of most other, generally more drastic, wrenching regimes (Duryea and Lavender 1982, Koon and O'Dell 1977 Menzies 1980, Tanaka and others 1975, Van Den Driessche 1983). Wrenching did not improve field survival, however; a finding consistent with results reported by Duryea and Lavender (1982) and Menzies (1980), but at variance with findings of Koon and O'Dell (1977), Tanaka and others (1975, 1976), and Van Den Driessche (1983). Field growth of seedlings was not improved by wrenching, as reported also for at least part of the tests by Duryea and Lavender (1982), Menzies (1980), and Van Den Driessche (1983).

In this study, lack of a wrenching effect on seedling field survival and growth might be due to the favorable first-year growing season. Moisture stresses may not have become sufficiently high to bring out differences. On such droughty sites, however, some degree of moisture stress is likely even when rainfall in the pronounced dry season is well above average. There are other possible explanations. Sites were free of snow in January so planting was earlier than usual, roots were active, and seedlings might have had several months to stabilize before being subjected to critical moisture stresses. Koon and O'Dell (1977) reported that internal water stresses were different in wrenched and unwrenched seedlings only for the first 45 days after planting. Finally, wrenching might not have been severe enough to perpetuate its effects for more than 6 months. Data from seedlings lifted periodically indicated that growth in the nursery during autumn months moderated early differences between wrenched and unwrenched seedlings. Although lack of replication of the wrenching treatment limited some statistical comparisons, regression equations clearly showed that major changes in seedling size occurred between wrenching and final lifting date.

Lifting date deserves emphasis for two reasons. The more time that elapses between wrenching and lifting, the more chance there is for wrenching effects to diminish because of growth and physiological changes that occur in both wrenched and unwrenched seedlings. The degree of change is dependent on the nursery practices applied subsequent to wrenching, on the seasonal top and root growth pattern for the nursery, on the weather in the particular season, and perhaps on other factors. Lifting date also has an important direct influence on subsequent seedling growth. Both wrenched and unwrenched seedlings that were lifted before they were dormant subsequently made less shoot growth than those that were fully dormant.

Wrenching is only one of the nursery practices that help condition seedlings for outplanting. Effect of seedbed density has been given some attention in wrenching studies, but other factors, particularly the irrigation regime, need more consideration. Effects of the same wrenching schedule on successive nursery crops and on field performance in different years also need to be determined. Studies to fill some of these gaps are in progress.

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Effects of wrenching Douglas-fir seedlings in August of their second season in the D. L. Phipps State Forest Nursery, Elkton, Oregon, were determined by periodic samplings to learn of changes in phenological, morphological, and growth characteristics. Initial effects of wrenching moderated by January when seedlings were lifted; both wrenched and unwrenched seedlings had grown substantially larger. Survival and growth of seedlings were good during the first 5 years after outplanting in droughty skeletal soil on southeast and northeast slopes in the South Umpqua River drainage of southwestern Oregon, and no significant differences were found between wrenched and unwrenched seedlings. A difference in total tree height on the two slopes was caused by greater browsing on the southeast slope.

Keywords: Regeneration, wrenching, nursery practices, seedling growth, browsing (-regeneration, Douglas-fir, *Pseudotsuga menziesii.*

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